# Relationships between yield and some structural traits of the laticiferous system in *Hevea* clones resistant to South American leaf blight

**Dominique Garcia*[1]; Vincent Le Guen[2]; Carlos Raimundo Reis Mattos[3]; Paulo de Souza Gonçalves[4] and André Clément-Demange[1]**

[1] Centre de Coopération International en Recherche Agronomique pour le Développement, Programme Hevea, Boulevard de la Lironde, Bât PSIII – 34398 Cedex 5 Montpellier, France; [2] CIRAD P.O. Box 701 97387 Kourou Cedex French-Guiana; [3] Plantações Michelin da Bahia, Caixa Postal 02, CEP 45435-000, Ituberá, BA, Brazil; [4] Instituto Agronômico de Campinas, Centro de Café e Plantas Tropicais, Av. Barão de Itapura, 1481, Caixa Postal 28, CEP 13001-970, Campinas, SP, Brazil. (* Corresponding Author. E-mail: dominique.garcia@br.michelin.com)

## ABSTRACT

Latex yield and six anatomical bark traits were measured in a five-year-old rubber tree clonal trial planted in Ituberá (Bahia, Brazil), on forty-nine different clones. The clones were pre-selected for resistance to SALB (South American Leaf Blight) caused by the fungus *Microcyclus ulei* (P.Henn.) v. Arx. The studied traits were : average yield (AY), girth (SC), virgen bark thickness (BT), total number of latex vessel rings (NR), average density of latex vessel per ring (DV), average diameter of latex vessels (DL) and average distance between consecutive latex vessel rings (AD). Phenotypic, genotypic and environmental correlations, and coefficient of genetic prediction (CGP) were calculated for all characters. There were considerable genetic variations between clones for AY, NR and BT, as indicated by high values of CGP. The genetic correlations were significant between AY and NR. The possibility to use NR as predictor of AY is discussed and the expected gains in percent of several references for AY are computed. FDR 4575, FDR 6099, FDR 5240, FDR 2010, FDR5597, CDC308, FDR 4151, CDC 943, MDX 608 clones were retained for their potential yield and recommended for multilocation large scale trials.

**KEY WORDS**: Latex production, latex vessel ring, yield predictor, rubber tree, breeding.

## INTRODUCTION

The first breeding projects for selection of South American leaf Bligh (SALB) resistant clones caused by the fungus, *Microcyclus ulei* (P.Henn) v.Arx., foliar pathogen of rubber tree [*Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell-Arg.], were developed in Latin America by the Ford Motor Company (Holliday, 1970; Sérier, 1993). In 1928, in an attempt to bypass the British monopoly on natural rubber, the Ford Motor Company began a rubber tree plantation program near Tapajoz river (Para, Brazil). From all the material, various species of *Hevea* were collected such as *H. brasilienses, H. benthamiana, H. spruceana* and *H. Guianensis*, among others .

From the year 1947, Firestone participated actively in the SALB resistant clone breeding program and collaborated with the exchanges of germplasm in Latin America. Genetic variability was assured by progenies from an F clones set (Ford prospection in the Amazonian basin), an Fx set (cross of F resistant clones with Asiatic high yielding clones), an IAN set (selection of Instituto Agronomico do Norte), an MDF set (selection on 25000 seedlings evaluated for SALB resistance and yield in Peru), and a TU set (selection of seedlings in the plantation of Turrialba in Costa Rica).

Two distinct breeding programs followed, one in Guatemala and the other in Liberia. In Guatemala, natural pollinations between MDF and Asiatic clones resulted in the production of twenty five thousand seedlings, from which MDX clones were selected (Madre Dios cross). Evaluated for their resistance and their yield, these clones were used as parents in controlled pollinations with the Asiatic clones. The new clones were named CD (resistant Dothidella Clones derived from hand pollinations) and CDC (same as CD, final C designates Clavellinas). In Liberia, Firestone imported the material presumed resistant from Latin America via the Coconut Groove Station in Florida. FDR clones (Firestone Dothidella Resistant) were created in this country, by selecting among seedlings originated either from open or from controlled pollinations.

Progressively, these breeding programs turned more extensive. Two supplementary stations completed the experimentation, Navajoa on the Atlantic coast of Guatemala and Fazenda Três Pancadas (F3P) in the State of Bahia, Brazil. Other breeding strategies were developed: GU clones (Guatemala) produced from controlled pollinations between F, IAN and Asiatic clones at Clavellinas, TP clones from illegitimate populations at Fazenda Três Pancadas.

In 1983, Firestone withdrew from the ongoing rubber breeding projects, leaving many yield and SALB resistance trials for this new breeding material incomplete. The seventy years of rubber breeding activities resulted in approximately six hundred original clones planted at the Fazenda Três Pancadas (renamed Plantação Michelin da Bahia – PMB – in 1994).

From these two South-American breeding programs, only few clones were recommended for large scale planting in Latin America due to their low latex production compared to the Asiatic clones and/or the breakdown of their resistance to *M. ulei* (Miller, 1966; Chee, 1976; Hashim and Almeida, 1987).

Simultaneously, in order to develop a more efficient methodology, *Hevea* breeding programs focused on production became interested in morphological and anatomical criteria such as trunk girth (Whitby, 1919; La Rue, 1920; Gomez et al., 1972; Narayanan et al., 1974; Hénon and Nicolas, 1989; Gonçalves et al., 1995), bark thickness (La Rue, 1920; Gomez et al., 1972; Narayanan et al., 1974; Hénon and Nicolas, 1989; Gonçalves et al., 1995), number of latex vessels rings (La Rue, 1920; Gomez et al., 1972; Hénon and Nicolas, 1989; Gonçalves et al., 1995), density and diameter of latex vessels (Gomez et al., 1972; Narayanan et al., 1974; Hénon and Nicolas, 1989; Gonçalves et al., 1995), average distance between consecutive latex vessel rings (Gomez et al., 1972; Narayanan et al., 1974; Gonçalves et al., 1995), sieve tube diameter (Gunnery, 1935; Champeix, 1947; Fernando and Tambiah, 1970; Azzini et al., 1998), or phloem zone thickness (Hénon, 1984). Results from these studies showed that latex production depended on the combination of all these morphological and anatomical parameters. For some clones, total yield was explained by these parameters, whereas for others, only a few characteristics were determined by these same parameters. According to these studies, the number of latex vessel rings character seems to be the most frequently correlated with yield. Physiological parameters also contribute to explain the latex yield (Bricard and Nicolas, 1989).

The objective of this article is to present a synthesis on clonal information concerning early tests for yield and characters from the laticiferous system originated from SALB resistant clones. Genetic parameters and correlation among characters are estimated in order to identify in this special population of clones the best parameter to explain yield variation.

## MATERIAL AND METHODS

### Plant material

The experimental trial was constituted of 100 clones planted in June 1993, at the Plantation Michelin of Bahia (PMB), Ituberá, Brazil, in an area of high SALB pressure. The statistical design consisted of three randomized blocks, with twelve trees per clone for each elementary plot.

These trees had been evaluated during five years for SALB resistance and growth. Simultaneously to the yield evaluation, the most resistant clones were tested under controlled conditions for infection with *Microcyclus ulei* polyvirulent strains.

### Test of latex production

The average yield (AY) was determined by registering the latex coagulum production. The tapping panel was opened at one meter from the soil for all trees with girth superior to 25 cm (five years after planting). Tapping in downward half-spiral spread from January to June 1998. Trees were tapped every four days and stimulated after the first cut every two months with ethephon 2.5% (Ethrel PT, 10% ethephon ).

Coagulum from all tapped trees from an elementary plot were joined and weighed monthly. Monthly values were added (January + March + May and February + April + June) and divided by the number of tapped trees. The analyzed data represent the coagulum production of a tree accumulated during three months (AY).

### Anatomical observations

Out of the one hundred clones evaluated during the trial, forty-nine clones considered most resistant to SALB were selected for observation of laticiferous structure. Their parentage and origin are presented in Table 1.

**Table 1**. Clones, selection program, country of origin, parental and type of cross-bredding of 49 *Hevea* clones studied in Ituberá, Bahia State, Brazil.

| Clone | Selection program | Origine country | Parental | Type of cross-breeding |
|---|---|---|---|---|
| CD 1101 | Firestone | Guatemala | Avros 1581 x MDF 72 | W x Primary Clone |
| CD 1161 | Firestone | Guatemala | Avros 1581 x MDF 72 | W x Primary Clone |
| CDC 273 | Firestone | Guatemala | MDX 17 x RRIM 509 | Wa x W |
| CDC 308 | Firestone | Guatemala | Avros 308 x MDX 40 | W x Wam |
| CDC 312 | Firestone | Guatemala | Avros 308 x MDX 40 | W x Wam |
| CDC 318 | Firestone | Guatemala | Avros 308 x MDX 40 | W x Wam |
| CDC 347 | Firestone | Guatemala | RRIM 614 x MDX 88 | W x Wam |
| CDC 358 | Firestone | Guatemala | MDX 17 x RRIM 614 | Wam x W |
| CDC 429 | Firestone | Guatemala | RRIM 600 x MDX 17 | W x Wam |
| CDC 56 | Firestone | Guatemala | MDX 91 x RRIM 614 | Wam x W |
| CDC 846 | Firestone | Guatemala | RRIM 600 x MDX 25 | W x Wam |
| CDC 919 | Firestone | Guatemala | RRIM 624 x MDX 25 | W x Wam |
| CDC 943 | Firestone | Guatemala | RRIM 614 x MDX 25 | W x Wam |
| CDC 986 | Firestone | Guatemala | Avros 1581 x GU 510 | W x (Wam ?) |
| F 4512 | Ford | | | Primary Clone *H. benthamiana* |
| FDR 2010 | Firestone | Liberia | Harbel 8 x IAN 3893 | W x (Wam x W) |
| FDR 3275 | Firestone | Liberia | Harbel 12 x IAN 3890 ? | W x [(*H. benthamiana* x W) x W] |
| FDR 4151 | Firestone | Liberia | RRIM 600 x IAN 6491 | W x (*H. pauciflora* x W) |
| FDR 4459 | Firestone | Liberia | Harbel 11 x MDF 363 | W x Primary Clone |
| FDR 4461 | Firestone | Liberia | Harbel 11 x MDF 363 | W x Primary Clone |
| FDR 4575 | Firestone | Liberia | Harbel 68 x FDR 18 | W x ? |
| FDR 4773 | Firestone | Liberia | Tjir 1 x IAN 3829 | W x [(*H. benthamiana* x W) x W] |
| FDR 5211 | Firestone | Liberia | Harbel 68 x TU 42-525 | W x Wam |
| FDR 5240 | Firestone | Liberia | Harbel 68 x TU 42-525 | W x Wam |
| FDR 5597 | Firestone | Liberia | Harbel 68 x TU 42-525 | W x Wam |
| FDR 5643 | Firestone | Liberia | RRIM 600 x IAN 6491 | W x [*H. Pauciflora* x W] |
| FDR 5680 | Firestone | Liberia | Harbel 8 x IAN 2829 | W x [(*H. benthamiana* x W) x W] |
| FDR 5763 | Firestone | Liberia | RRIM 600 x GU 198 | W x [W x (Primary Clone x W)] |
| FDR 5788 | Firestone | Liberia | Harbel 8 x MDF 180 | W x Primary Clone |
| FDR 5794 | Firestone | Liberia | Harbel 65 x CD 41 | W x ? |
| FDR 5894 | Firestone | Liberia | Harbel 8 x IAN 2829 | W x [(*H. benthamiana* x W) x W] |
| FDR 6095 | Firestone | Liberia | FX 2261 x ? | (Clone primaire x W) x ? |
| FDR 6099 | Firestone | Liberia | FX 3899 x ? | (*H. benthamiana* x W) x ? |
| FX 2784 | Ford | | F4542 x Avros 363 | *H. benthamiana* x W |
| MDF 180 | Firestone | Peru | | Clone primaire |
| MDX 15 | Firestone | Guatemala | Tjir 1 x MDF ? | W x Wam ? |
| MDX 239 | Firestone | Guatemala | Avros 338 x 93393 | W x Wam ? |
| MDX 25 | Firestone | Guatemala | Avros 308 x MDF ? | W x Wam ? |
| MDX 45 | Firestone | Guatemala | Avros 1581 x MDF ? | W x Wam ? |
| MDX 608 | Firestone | Guatemala | Avros 1581 x MDF ? | W x Wam ? |
| MDX 87 | Firestone | Guatemala | Avros 308 x MDF ? | W x Wam ? |
| MDX 98 | Firestone | Guatemala | Avros 308 x MDF ? | W x Wam ? |
| RO38 (alias FX 3899) | Ford | | F4542 x Avros 363 | *H. benthamiana* x W |
| SIAL 893 | IAL | Brazil | | PB 86 illegitimate |
| TP 1003 | Firestone | F3P | - | - |
| TP 1004 | Firestone | F3P | - | - |
| TP 39 | Firestone | F3P | - | - |
| TP 749 | Firestone | F3P | - | - |
| TP 875 | Firestone | F3P | - | - |

AVROS : Algemene Vereniging Rubberplanters Oostkust Sumatra; CD and CDC : Clones derived from hand pollinations between SALB (Dothidella) resistant and SALB susceptible clones, final C designates Clavellinas; F : Ford; FDR : Firestone Dothidella Resistance; Fx : Ford Cross; IAL : Instituto Agonômico de Leste; IAN : Instituto de pesquisas Agropecuárias do Norte; MDF : Madre de Dios Firestone; MDX : Madre de Dios Cross; RRIM : Rubber Research Institute of Malaysia;RO : Rondonia; SIAL : Seleção Instituto Agronômico do Leste; Tjir : Tjirandji; TP : Três Pancadas; TU : Turrialba, Costa Rica; W : Wickham clones; Wam : Clone from Wickham x Amazonian cross.

Bark samples were taken from the trunk, at 1.20 m from the soil on the opposite side to the tapping panel. Samples of two trees per plot and per clone were analyzed. Some longitudinal and transverse cuts were made in the samples which were then stained with Sudan III and osmic acid to determine the following characters:

· Number of latex vessels rings (NR) determined from longitudinal-radial cuts (units) ;

· Average density of latex vessels per ring per five millimeter of bark (DV). The second coat was chosen on the radial longitudinal section (units) ;

· Average diameter of latex vessels (DL), observed through the longitudinal-radial section (µm) ;

· Average distance (AD) between two consecutive vessels rings (µm) ;

· Virgin bark thickness (BT) in mm was measured using an awl (steel hits) at one meter height from the soil ;

The girth (SC) had been valued at 1.20 m from the soil.

**Estimation of genetic parameters**

Data were analyzed using the DIOGENE software (Baradat and Labbé, 1995). Analysis of variances, genetic prediction coefficients and correlation coefficients were estimated with confidence intervals at 5%, by the " jacknife " method described by Baradat et al. (1995). For each analysis, 5% of the total effective were ramdomly sampled. Three hundred draws were realized.

The ANOVA model in Table 2 was applied for overall comparisons. Variance components were calculated through 'expected mean square' components given in Table 2.

The analysis were carried out according to the following statistical model:

$Y_{jk} = \mu + C_j + E_{jk}$ where,

$Y_{jk}$ = observed value of j $^{th}$ clones in the k $^{th}$ replication, $\mu$ = general mean, $C_j$ = effect of j$^{th}$ clone (j = 1, 2,… .49), $E_{jk}$ = experimental error associated with jk$^{th}$ observation (k = 1, 2, 3).

The Coefficients of Genetic Prediction (*CGPs*) were estimated for the seven traits. The CGP concept involves the generalisation of heritability when two traits are considered. Baradat (1976) gave this name to the standardized regression of the genetic value of one trait on the phenotypic value of another trait (the values are expressed into phenotypic standard deviations), based on Nei (1960) and his definition of 'co-heritability'.

Considering the q x q matrix of *CGPs* concerning q traits, the ratio of diagonal *CGP* of trait *l* (heritability of this trait) on an off-diagonal *CGP*, the relative efficiency of the selection of trait *l* using *l'* as a predictor can be given directly.

The *CGPs* were computed as follow :

$$C\hat{G}P^{(l,l')} = \frac{\hat{\text{cov}}_g^{(l,l')}}{\sqrt{\hat{\sigma}_g^{2(l)} + \hat{\sigma}_e^{2(l)}}\sqrt{\hat{\sigma}_g^{2(l')} + \hat{\sigma}_e^{2(l')}}}\text{, where}$$

$C\hat{G}P^{(l,l')}$: coefficient of genetic prediction for the traits *l* and *l'*; $\hat{\sigma}_g^{2(l)}$, $\hat{\sigma}_g^{2(l')}$: genetic variance among clones for the traits *l* and *l'*; $\hat{\sigma}_e^{2(l)}$, $\hat{\sigma}_e^{2(l')}$: environmental variance among plots for the traits *l* and *l';* $\hat{\text{cov}}_g^{(l,l')}$: covariance due to differences among clones for the traits *l* and *l'*.

By stating : *l*=*l*', one can find the heritability formulae which is redefined as the CGP of a trait with itself : the covariance of the numerator becomes the corresponding variance of trait *l*.

To determine the degree of association between character pairs, Pearson's correlation coefficients $\rho_{x_l x_{l'}}$ were calculated with the following equation :

$$\rho_{x_l x_{l'}} = \frac{\sigma_{x_l x_{l'}}}{\sigma_{x_l}\sigma_{x_{l'}}}$$

**Table 2**. Degrees of freedom (D.F.), expected mean square (EMS) and expected mean covariance product (EMCP) for estimating components of variance, covariance and heritabilities in rubber tree clones.

| Source of variation | D.F. | EMS | EMCP |
|---|---|---|---|
| Replications | r-1 | | |
| Genotypes | g-1 | $\sigma^2_e + r\sigma^2_g$ | $\sigma_{eij} + r\sigma_{gij}$ |
| Interaction clones x replications | (r-1) (g-1) | $\sigma^2_e$ | $\sigma_{eij}$ |

$\sigma^2_e$ = Variance due to interaction between clones and replications; $\sigma^2_g$ = Variance due to differences among clones; r = number of replications; g = number of clones; σeij = covariance due to interaction between clones and replications of *i* and *j* characters; σgij = covariance due to clones for *i* and *j* characters.

**Table 3**. Overall means ( $\overline{x}$ ), standard deviation (sd), coefficient of variation (CV%) for seven studied yield characters from 49 rubber tree clones grown in Ituberá, BA, Brazil..

| Characters | $\overline{x}$ | **Range** | **Units** | **sd** | **C.V. %** |
|---|---|---|---|---|---|
| Average Yield (AY) | 288 | 20 - 677 | g/tree | 129.89** | 15.32 |
| Stem circumference (SC) | 42.54 | 24 – 63.5 | cm | 6.64** | 11.95 |
| Virgen bark thickness (BT) | 5.21 | 3.17 – 7.52 | mm | 0.86** | 12.30 |
| Total number of latex vessel rings (NR) | 10.28 | 4 - 21 | unit | 3.04** | 17.42 |
| Overall density of latex vessel per ring (DV) | 10.19 | 4.62 – 14.11 | unit | 1.20* | 10.29 |
| Average diameter of latex vessels (DL) | 26.43 | 15.90 – 35.33 | μm | 3.37** | 11.10 |
| Average distance between consecutive latex vessel rings (AD) | 304.08 | 127 - 653 | μm | 96.82** | 23.29 |

* = P<0.05; ** = P< 0.0001

where *x* will be replaced by P, G and E to get phenotypic, genetic and environmental correlations. The genetic and environmental covariances between two characters are calculated from the results of a multivariable analysis comparable to the simple variance analysis (Gallais, 1990). Mean squares are substituted by mean products, and variances by covariances.

Best Linear Predictor – BLP –selection indices for culling the best genotypes on the basis of a linear combination of C predicted traits were computed, following the general model :

$$I = \sum_{l=1}^{C} b_l \hat{g}_i(x_l)$$

where $\hat{g}_i(x_l)$ is the predicted average genetic value of the genotype *i* for trait $x_l$ and $b_l$ is the relative weight associated to this trait.

Genetic gains were appraised for a rate of selection of 50, 20, 10, 5 and 1%. Gains (ΔG) are given in percentage of a reference mean with the following formula :

$$\Delta G_{/\mu} = 100 \times \frac{G-\mu}{\mu}$$ , where

*G* = genetic mean of the selected clones ;

$\mu$ = general phenotypic mean or reference clones mean.

In the present study, we chose the general mean of the 49 studied clones and the means of some reference clones (Fx 2261, Fx 2784, Fx 3028, Fx 3864, Fx 4098).

### Multiple regression

The multiple regression was processed by the SAS system (SAS Institute, 1989) on phenotypic values, using the stepwise selection procedure for the dependent variable AY, to estimate how much SC, BT and the characters of the laticiferous system, i.e. NR, explain yield variation.

## RESULTS AND DISCUSSION

### Means and variation

The mean, range and coefficient of variation for each character are given in Table 3. The differences among clones were highly significant for all studied characters (Pr < 0.05). All the characters exhibited a considerable range in their expression. The coefficient of variation was the highest for the average distance between consecutive vessel rings (AD). The average yield (AY) and the number of latex vessel rings (NR) also showed considerable experimental coefficient of variation.

### Variances and Coefficients of Genetic Prediction

Genotypic variance, environmental variance and coefficients of genetic prediction (CGP) for the different traits are shown in Table 4. The CGP varied between 0.657 and 0.143 for the various characters, and the highest were obtained for AY, NR and BT (respectively, 0.657, 0.57 and 0.444). The CGP was

**Table 4**. Genotypic variances ( $\sigma_g^2$ ), environmental variances ( $\sigma_e^2$ ) and coefficients of genetic prediction (*CGP*) for average yield (AY), girth (SC), virgin bark thickness (BT), total number of latex vessel rings (NR), overall density of latex vessel per ring (DV), average diameter of latex vessels (DL) and average distance between consecutive latex vessel rings (AD) of 49 rubber tree clones.

| Genetic parameters | Characters | | | | | | |
|---|---|---|---|---|---|---|---|
| | AY (g/tree) | SC (cm) | BT (mm) | NR (unit) | DV (unit) | DL (μm) | AD (μm) |
| $\sigma^2_g$ | 10 781 | 8.5 | 32.9 | 5.26 | 0.207 | 2.48 | 3557 |
| | (1226) | (2.7) | (5.7) | (0.75) | (0.104) | (0.79) | (799) |
| $\sigma^2_e$ | 5629 | 31.4 | 0.41 | 3.97 | 1.24 | 8.75 | 5970 |
| | (566) | (5.0) | (0.04) | (0.38) | (0.20 | (0.85) | (694) |
| *CGP* | 0.657 | 0.213 | 0.444 | 0.570 | 0.143 | 0.221 | 0.373 |
| | (0.037) | (0.065) | (0.060) | (0.045) | (0.079) | (0.063) | (0.062) |

Standard error are in the brackets

the lowest for DV, SC and DL (respectively, 0.143, 0.213 and 0.221). The Brazilian literature on *Hevea* makes references to comparative studies on the heritability estimations of these traits (Gonçalves et al., 1996; Costa et al., 2000). Heritability in AY is always higher than heritability on the characters of the laticiferous system. According to Gallais (1990), effective indirect breeding needs predictors that exhibit a heritability higher than the predicted. Therefore, on adult trees, a clone selection based on yield observed values than on predicted values computed from parameters of the laticiferous system is recommended.

## Relationship studies

### Correlations

Phenotypic correlation was positive and medium between AY and NR (Table 5). AY was also phenotypically correlated with DV and AD. Only NR, AD, DL and DV were genetically correlated with AY (Table 6). The environmental correlation of AY with other characters were not significant (Table 7). These observations were not in accordance with the results of Vasconcellos (1982) or Gottardi et al. (1995) who reported low association between AY and NR. Narayanan et al. (1974) and Gonçalves et al. (1984), however, reported strong positive correlation between AY and BT. This difference may be due to the genetic origin of the studied material. The material described by these authors generally consisted of progenies issuing from crosses between high yielding clones. On the other hand, the clonal material studied here was obtained by selecting ortets from progenies of cross pollinations between high yielding and SALB resistant clones. Furthermore, the latter parents consisted mostly of clones directly issued from a wild germplasm or separated from it by one or two generations of breeding. Compared to the Asiatic clones which were obtained from a narrow genetic base (Wickham population) after various generations of breeding, the material used in this study was indeed much less genetically homogeneous. The large variation observed in the NR permits the detection of a significative correlation with AY.

Among the characters of the laticiferous system, some were both phenotypically and genetically correlated, as in the case of BT with DV and BT with DL. These results indicate that the virgin bark thickness is more connected to the structure of the vessel (diameter, density) than to the total number of vessel rings.

Girth did not show significant genetic correlation with any of the characters studied, indicating independent genetic control of vigor. This also implies that high AY and high vigor could be combined in a single genotype. Gonçalves et al. (1996) also reported low correlation among these characters in young rubber open pollinated progenies.

### *Multiple regression*

To explain yield variation, multiple regression was processed on phenotypic values using AY as a dependent variable and SC, BT and the characters of the laticiferous system as independent variables (Table 8). In this equation, NR accounted for 27% of the variation in yield. Compared to NR, other variables were less important to explain yield variation in this clones combining resistance and production.

On half-sib progenies obtained from high yield clones, Gonçalves et al. (1995) showed that DV and DL were the main variable , accounting for 41% –

**Table 5**. Phenotypic correlation among average yield (AY), girth (SC), virgin bark thickness (BT), total number of latex vessel rings (NR), overall density of latex vessel per ring (DV), average diameter of latex vessels (DL) and average distance between consecutive latex vessel rings (AD) in 49 rubber tree clones.

| Characters | SC | BT | NR | DV | DL | AD |
|---|---|---|---|---|---|---|
| **AY** ± SE | 0.120 ± 0.063 | 0.186 ± 0.067 | 0.517 ± 0.043 | 0.230 ± 0.059 | 0.204 ± 0.060 | -0.216 ± 0.054 |
| *Signif (%)* | *5.461* | *0.578* | *0.000* | *0.017* | *0.085* | *0.013* |
| **SC** ± SE | | 0.459 ± 0.046 | 0.295 ± 0.053 | 0.214 ± 0.062 | 0.007 ± 0.059 | -0.163 ± 0.063 |
| *Signif (%)* | | *0.000* | *0.000* | *0.085* | *1.355* | *2.713* |
| **BT** ± SE | | | 0.304 ± 0.055 | 0.366 ± 0.052 | 0.320 ± 0.053 | 0.091 ± 0.062 |
| *Signif (%)* | | | *0.000* | *0.000* | *0.000* | *13.834* |
| **NR** ± SE | | | | 0.303 ± 0.059 | 0.397 ± 0.049 | -0.527 ± 0.040 |
| *Signif (%)* | | | | *0.000* | *0.000* | *0.000* |
| **DV** ± SE | | | | | 0.303 ± 0.057 | -0.143 ± 0.055 |
| *Signif (%)* | | | | | *0.000* | *2.599* |
| **DL** ± SE | | | | | | -0.072 ± 0.061 |
| *Signif (%)* | | | | | | *1.180* |

**Table 6**. Genetic correlations among average yield (AY), girth (SC), virgin bark thickness (BT), total number of latex vessel rings (NR), overall density of latex vessel per ring (DV), average diameter of latex vessels (DL) and average distance between consecutive latex vessel rings (AD) in 49 rubber tree clones.

| Characters | SC | BT | NR | DV | DL | AD |
|---|---|---|---|---|---|---|
| **AY** ± SE | 0.042 ± 0.015 | 0.203 ± 0.110 | 0.713 ± 0.062 | 0.590 ± 0.176 | 0.576 ± 0.136 | -0.442 ± 0.101 |
| *Signif (%)* | *77.602* | *6.233* | *0.000* | *0.108* | *0.006* | *0.004* |
| **SC** ± SE | | -0.125 ± 0.197 | -0.027 ± 0.161 | -0.054 ± 0.332 | -0.179 ± 0.264 | -0.090 ± 0.172 |
| *Signif (%)* | | *53.438* | *85.926* | *86.642* | *50.516* | *60.750* |
| **BT** ± SE | | | 0.102 ± 0.114 | 0.804 ± 0.167 | 0.599 ± 0.141 | 0.400 ± 0.133 |
| *Signif (%)* | | | *62.461* | *0.001* | *0.006* | *3.007* |
| **NR** ± SE | | | | 0.465 ± 0.166 | 0.548 ± 0.610 | -0.781 ± 0.070 |
| *Signif (%)* | | | | *2.800* | *5.487* | *0.000* |
| **DV** ± SE | | | | | 0.910 ± 0.231 | -0.006 ± 0.210 |
| *Signif (%)* | | | | | *0.016* | *97.414* |
| **DL** ± SE | | | | | | -0.122 ± 0.170 |
| *Signif (%)* | | | | | | *51.933* |

**Table 7**. Environmental correlations among average yield (AY), girth (SC), virgin bark thickness (BT), total number of latex vessel rings (NR), overall density of latex vessel per ring (DV), average diameter of latex vessels (DL) and average distance between consecutive latex vessel rings (AD) in 49 rubber tree clones.

| Characters | SC | BT | NR | DV | DL | AD |
|---|---|---|---|---|---|---|
| **AY** ± SE | 0.202 ± 0.074 | 0.176 ± 0.077 | 0.211 ± 0.065 | 0.091 ± 0.055 | -0.030± 0.073 | 0.006 ± 0.063 |
| *Signif (%)* | *0.689* | *2.195* | *0.145* | *9.233* | *68.483* | *92.044* |
| **SC** ± SE | | 0.752 ± 0.033 | 0.523 ± 0.050 | 0.272 ± 0.064 | 0.152 ± 0.070 | -0.197 ± 0.071 |
| *Signif (%)* | | *0.000* | *0.000* | *0.005* | *2.946* | *0.599* |
| **BT** ± SE | | | 0.517 ± 0.052 | 0.236 ± 0.067 | 0.202 ± 0.076 | -0.121 ± 0.076 |
| *Signif (%)* | | | *9.891* | *0.057* | *0.848* | *10.668* |
| **NR** ± SE | | | | 0.280 ± 0.062 | 0.312 ± 0.067 | -0.321 ± 0.064 |
| *Signif (%)* | | | | *0.002* | *0.001* | *0.000* |
| **DV** ± SE | | | | | 0.174 ± 0.070 | -0.193 ± 0.069 |
| *Signif (%)* | | | | | *1.314* | *0.564* |
| **DL** ± SE | | | | | | -0.053 ± 0.071 |
| *Signif (%)* | | | | | | *53.373* |

**Table 8.** Stepwise multiple regression of the dependent variable average yield (AY) on girth (SC), virgin bark thickness (BT), total number of latex vessel rings (NR), overall density of latex vessel per ring (DV), average diameter of latex vessels (DL) and average distance between consecutive latex vessel rings (AD) of bark samples taken from 49 rubber tree clones.

| Independent variable | Intercept | $R^2$ |
|---|---|---|
| 22.38*NR | 55.723 | 0.2738 |
| (2.16) | | |
| 21.54*NR + 7.16$^{ns}$ DV | -8.769 | 0.2779 |
| (2.26) (5.69) | | |
| 23.13*NR + 7.05$^{ns}$ DV + 0.093$^{ns}$ AD | -52.435 | 0.2814 |
| (2.63) (5.69) (0.079) | | |
| 24.15*NR + 8.31$^{ns}$ DV + 0.107$^{ns}$ AD – 2.19$^{ns}$ DL | -22.046 | 0.2814 |
| (2.82) (5.83) (0.080) (2.20) | | |
| 24.41*NR + 8.62$^{ns}$ DV + 0.107$^{ns}$ AD – 2.27$^{ns}$ DL – 0.407$^{ns}$ SC | -8.373 | 0.2842 |
| (2.91) (5.90) (0.080) (2.21) (1.089) | | |
| 24.29*NR + 8.33$^{ns}$ DV + 0.102$^{ns}$ AD – 2.35$^{ns}$ DL – 0.508$^{ns}$ SC + 1.93$^{ns}$ BT | -6.176 | 0.2843 |
| (2.99) (6.09) (0.085) (2.25) (1.209) (9.94) | | |

$R^2$ = coefficient of determination; *P<0.001; ns = not significant. Figures within brackets are the standard error of respective regression coefficients.

49% of variation in yield. NR did not play an important rule in determining yield in young plants. In Malaysia, nearly 80% of the yield variation found in clones at the nursery stage were associated to BT, NR, girth increment and plugging index variations (Narayanan et al., 1974).

In mature trees, Ho et al. (1973) observed that NR was an important structural yield determinant. According to Wycherley (1969), NR was responsible for 25% to 50% of the yield variation between genotypes. In India, Licy and Premakumari (1988) explained 43% of variation in nursery yield by NR, plant height and BT.

According to the several high correlations found between NR and yield in mature trees (Frey-Wyssling, 1930; Riches and Gooding, 1952, Narayanan et al., 1973), the significant and positive correlation between AY and NR obtained in this paper indicates that NR could usefully be employed as a culling criteria to select the most productive plants between semi-wild clones or progenies.

### Clone selection

Table 9 shows the genetic gains on AY, for various selection percentages, with or without NR as a predictor. The best gain on AY was obtained by using NR as predictor with a coefficient of 0. The additional gain using NR as predictor was not representative. As indicated before, due to high heritability yield does not require the use of the other parameters to carry out indirect selection on adult trees. On the other hand, for an indirect selection on yield on immature trees, the variable NR should be considered. And, if a relationship between yield and NR is detected, the determination on one year-old SALB resistant clones is recommended.

Results from the comparative studies carried out with some control clones present in the same experiment showed that genetic gain in the selected population could be superior to the yield for all selection levels. It is important to emphasize that three control clones (Fx 2261, Fx 3864 and Fx 4098) were recommended during the PROBOR period (Programa de incentivo à Produção de Borracha). However, due to their lack of resistance to the conditions offered by the state of Bahia, they never reached the production level expected.

Table 10 compares the results from a yield phenotypic values selection to an index selection. Both selection types retained the same clones , i.e., genetic values were well predicted by phenotypic values. With a selection of 18%, the clones FDR 4575, FDR 6099, FDR 5240, FDR 2010, FDR 5597, CDC 308, FDR 4151, CDC 943 and MDX 608 were retained. The next step in our breeding program will be to carry out an experiment with these clones on multilocal large scale trials to check resistance and production predictions.

## CONCLUSIONS

Results from the present study have shown that NR could be a good predictor of AY in breeding programs

**Table 9.** Yield genetic gains ($\Delta G$) for various percentages of selection using or no « total number of latex vessel rings » as predictor.

| Genetic gain | Coefficient | Selection : 50% | 20% | 10% | 5% | 1% |
|---|---|---|---|---|---|---|
| $\Delta G_{/\mu}$ * | AY =1 | 29 | 51 | 64 | 75 | 97 |
| $\Delta G_{/\mu}$ | AY =1 ; NR=1 | 29 | 51 | 64 | 76 | 98 |
| $\Delta G_{/\mu}$ | AY =1 ; NR=0 | 32 | 57 | 71 | 83 | 107 |
| $\Delta G_{/\mu_{Fx2261}}$ | AY =1 ; NR=0 | 184 | 236 | 267 | 294 | 346 |
| $\Delta G_{/\mu_{Fx2784}}$ | AY =1 ; NR=0 | 141 | 185 | 212 | 235 | 278 |
| $\Delta G_{/\mu_{Fx3028}}$ | AY =1 ; NR=0 | 163 | 211 | 239 | 264 | 312 |
| $\Delta G_{/\mu_{Fx3864}}$ | AY =1 ; NR=0 | 237 | 299 | 335 | 367 | 430 |
| $\Delta G_{/\mu_{Fx4098}}$ | AY =1 ; NR=0 | 72 | 103 | 122 | 138 | 170 |

* Genetic gains represent a percentage of a reference mean : $\mu$ , yield general mean of the studied population ; $\mu_{Fx\ 2261}$, yield mean of the clone Fx 2261.

**Table 10.** Comparison of phenotypic average yield (g/tree) of 49 rubber tree clones with selection index (calculated using NR total number of latex vessel rings (NR) as predictor character with a coefficient of 0 and average yield as predicted character with a coefficient of 1).

| Clone | Phenotypic Average | Index | Clone | Phenotypic Average | Index | Clone | Phenotypic Average | Index |
|---|---|---|---|---|---|---|---|---|
| FDR 4575 | 537* | 2.35* | TP 875 | 326 | 0.26 | FDR 4459 | 212 | -0.73 |
| FDR 6099 | 509* | 2.10* | FDR 5794 | 323 | 0.21 | CDC 312 | 209 | -0.68 |
| FDR 5240 | 467* | 1.62* | FDR 5211 | 322 | 0.27 | MDX 239 | 192 | -0.96 |
| FDR 2010 | 461* | 1.62* | CDC 429 | 320 | 0.28 | CD 1161 | 187 | -0.93 |
| FDR 5597 | 455* | 1.72* | CDC 56 | 301 | 0.10 | FDR 4773 | 263 | -1.92 |
| CDC 308 | 435* | 1.42* | MDX 45 | 299 | 0.01 | MDX 25 | 174 | -1.13 |
| FDR 4151 | 407* | 1.09* | CD 1101 | 294 | 0.04 | MDX 87 | 172 | -1.10 |
| CDC 943 | 400* | 0.91* | FDR 5643 | 266 | -0.26 | FDR 5763 | 171 | -1.00 |
| MDX 608 | 396* | 0.89* | CDC 273 | 265 | -0.19 | FX 2784 | 158 | -1.20 |
| RO 38 | 376 | 0.82 | TP 749 | 265 | -0.05 | TP 39 | 148 | -1.16 |
| FDR 5894 | 361 | 0.76 | FDR 5788 | 264 | -0.23 | F 4512 | 138 | -1.47 |
| CDC 919 | 353 | 0.55 | TP 1003 | 249 | -0.35 | CDC 986 | 198 | -1.98 |
| MDX 15 | 344 | 0.50 | FDR 5680 | 248 | -0.41 | MDF 180 | 124 | -1.56 |
| FDR 6095 | 343 | 0.51 | MDX 98 | 242 | -0.44 | TP 1004 | 115 | -1.60 |
| FDR 3275 | 342 | 0.56 | CDC 347 | 240 | -0.48 | SIAL 893 | 104 | -3.79 |
| CDC 846 | 334 | 0.35 | FDR 4461 | 235 | -0.52 | CDC 318 | 88 | -1.81 |
| CDC 358 | 333 | 0.36 | | | | | | |

carried out on a semi-wild population of five year-old rubber trees. However, in order to identify early production indicators, it would be necessary to determine whether the same correlation exists between these two variables on younger trees. Finally, one of the contributions of this study was to allow for the selection of the following clones according to their resistance to *Microcylcus ulei* and their yield potential: FDR 4575, FDR 6099, FDR 5240, FDR 2010, FDR5597, CDC308, FDR 4151, CDC 943, MDX 608.

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## RESUMO

**Relações entre produtividade e alguns caracteres estruturais do sistema laticífero em clones de *Hevea* resistentes ao SALB**

A produção de látex e seis caracteres anatômicos da casca foram avaliados em seringueira de cinco anos de idade num ensaio plantado em Itubera (Bahia, Brasil) sobre quarenta e nove clones diferentes. Estas árvores foram pre-selecionadas para resistência ao SALB (South American Leaf Blight) causado pelo fungo *Microcyclus ulei* (P.Henn.) v. Arx. Os caracteres analisados foram a produção média (AY), a circunferência do caule (SC), a espessura da casca (BT), o número total de anéis de tubos laticíferos (NR), a densidade média do tubos laticíferos por anéis (DV), o diâmetro médio dos tubos laticíferos (DL) e a distância média entre dois anéis consecutivos (AD). As correlações fenotípicas, genotípicas, ambiental e os indices de determinação genotípica (CGP) foram calculadas para cada caráter. Houve variação significativa entre os clones para AY, NR e BT como indicam os valores elevados obtidos para o CGP. As correlações genéticas aparecem significativas entre AY e NR. A possibilidade de usar NR como um predictor de AY é discutida, e os ganhos genéticos de AY em porcentagem de várias referências são calculados. Os clones FDR 4575, FDR 6099, FDR 5240, FDR 2010, FDR 5597, CDC 308, FDR 4151, CDC 943, MDX 608 são selecionados com base no potencial de produção e sugeridos para multi-local experimentações em grande escala.

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